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A NEW HIGH-SPEED CATHODE-RAY TUBE

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ABSTRACT

A cathode-ray tube, DuMont type K1056, has been developed to fulfill the need for simplifying the recording of transient waveforms that require spot velocities of 3,000 in./μsec and higher. The K1056 was developed jointly by the Vacuum Tube Division of the Allen B. DuMont Laboratories, Inc., and the Naval Research Laboratory.

The evolution of the K1056 design required consideration of such design parameters as tube-envelope dimensions, electrode connections, deflection-plate configuration, screen-phosphor type, screen thickness, and sizes and spacings of beam-forming elements. The effects of spurious screen illumination and transit time were determined experimentally.

Full information on the characteristics (operating voltages, interelectrode capacitances, etc.) is presented. Typical operating voltages are 7.5 kilovolts on the second anode and 30 kilovolts on anode three.

To judge the performance of a cathode-ray tube, it was necessary to devise a figure of merit that is numerically equal to the resolution of the screen display. Sample photographs of K1056 traces show sine waves with frequencies of 200, 6,500, and 10,000 megacycles.

PROBLEM STATUS

This is a final report on one phase of the problem; work continues on other phases.

AUTHORIZATION

NRL Problem H09-01

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INTRODUCTION

As the art of electronics progresses, the need to obtain permanent records of transient-voltage waveforms constantly arises. Furthermore, the demand is for a means of recording waveforms with increased rates of rise or decay, thus requiring increased writing-speed capability of the recording setup. To satisfy this demand, recent improvements have been made both in cathode-ray tubes and in photographic techniques. The cathode-ray tubes developed in recent years for the display of high-speed traces are exemplified by the DuMont types 5RP-A,* K1017, K1032, and finally the K1056,† the tube described in this report. When compared with its predecessors, the K1056 provides improved resolution, greater useful screen area, and minimum distortion and background illumination, in addition to increased writing-speed capability. A sample production tube is shown in Figure 1.

DEVELOPMENT

During the development of the K1056, a total of 48 experimental tubes were fabricated for testing and evaluation. An analysis of the results obtained with each experimental model was used to establish the next line of attack. At the start of the investigation, the

Figure 1 - DuMont type-K1056 cathode-ray tube

* Lempert, I.E., and Feldt, R., "The 5RP Multiband Tube: An Intensifier-Type Cathode-Ray Tube for High-Voltage Operation," Proc. I.R.E., 34:432-440, 1946

† These experimental cathode-ray tubes were built by the Vacuum Tube Division of the Allen B. DuMont Laboratories, Inc., under Office of Naval Research Contract N9-onr-94700.

5-in. screen diameter was chosen from purely practical considerations. It also was clear that the multiband postdeflection-accelerating electrode arrangement would be required in order to use a high over-all tube voltage and yet maintain a reasonable deflection factor (volts per inch). Owing to previous difficulties that resulted from non-uniform screen-charge distribution on uncoated screens, it was decided initially that the screen would have an aluminized backing connected to the full tube potential.

From the standpoint of application as well as that of manufacture, it is desirable to minimize the length of a cathode-ray-tube envelope. Consequently, the first four experimental models had an over-all length of 17 in., and the throw from the deflection plates to the screen was 11 in. Owing to the required greater beam-deflection angle as compared with that of a tube having a longer plate-to-screen throw, these first tubes had several deficiencies: (a) excessive trace distortion (deflection nonlinearity), (b) insufficient usable screen area, and (c) defocusing of the spot when deflected from the center of the screen. On deflection from the axial position, all electrons in a beam cross section do not experience the same net accelerating force. Figure 2 shows that because of field fringing, the electrons nearer a deflection plate travel through the deflecting field along a path shorter than that followed by electrons diametrically opposite. This means that the deflected beam is focused at a point considerably short of the screen. Hence, if the undeflected beam is focused on the screen, defocusing occurs at deflected positions. Subsequent models, therefore, had greater bulb lengths, the final design having a nominal 21-in. over-all length and a 15-in. throw. The first experimental tubes had a new feature that was retained in the final model; the intensity-grid and cathode leads were brought out directly through the glass neck of the tube. This lead arrangement effects a reduction in the grid-cathode capacitance and the associated lead inductances—important considerations in the application of fast blanking or unblanking signals.

In an attempt to increase deflection linearity with unbalanced signals, a deflection-plate design called the "box plate" was incorporated in several sample tubes. One of a pair of plates was a plane surface; the other plate had a parallel planar section; and, in addition, the two edges parallel to the electron-beam axis were folded inward at 90 degrees. This box-plate configuration was used in an attempt to maintain deflection linearity with an unbalanced-to-ground deflection signal. Tubes utilizing this plate structure showed severe distortion of the trace near maximum deflection and exhibited an aggravation of the defocusing with deflection. In view of these results, it was decided that a symmetrical plate structure would be used. This provides a balanced-signal display with minimum distortion as well as good reproduction of unbalanced signals.

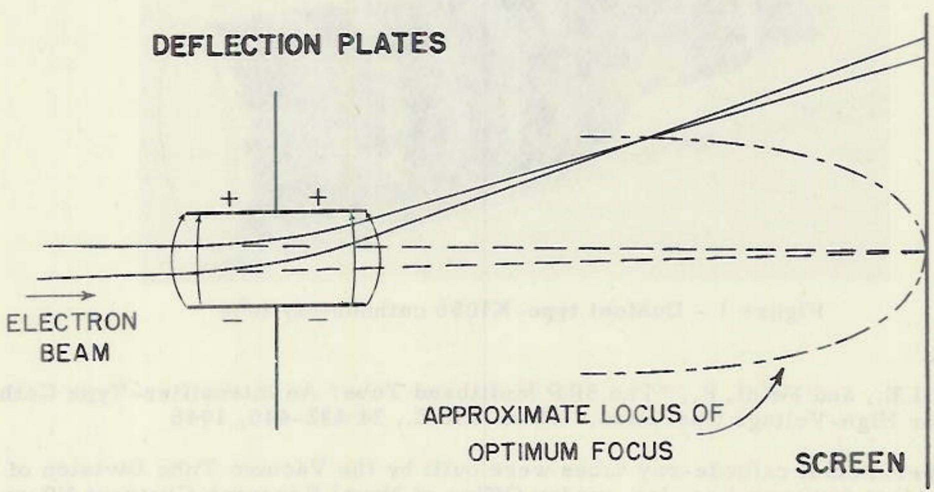

Figure 2 - Deflection defocusing

Because of the deterioration of spot focus when the beam was deflected from the center portion of the tube, an investigation of the use of curved faceplates was undertaken. The use of a fluorescent screen surface that is convex outward would, at least partly, correct for field curvature of camera lenses.* However, this study showed that, as far as the electron optics are concerned, essentially no improvement accrues in using other than a flat screen area on a cathode-ray tube having a multiband postdeflection acceleration. The electron beam of such tubes must follow a doubly inflected path so that, on arrival at the screen, parallelism is maintained regardless of beam deflection. Consequently, the K1056 cathode-ray tube has an optically flat glass faceplate.

To determine the effect of the type and thickness of the screen phosphor, tubes with different thicknesses of P7 and P11 screen materials were tested. Only the short-persistence portion of the P7 screen was used. The thickness, as measured by the transmission of light from an incandescent source through the screen, was varied from 40 to 60 percent in 5-percent increments. The P11 material was generally superior, and the optimum thickness was found to be that corresponding to a light transmission of 53 percent.

Trouble has been encountered, both in previous tubes and in experimental K1056's, with regard to spurious screen illumination. Such illumination falls into two categories: steady illumination (stray emission) and illumination under control of the intensity grid (bloom). Much effort has been expended toward the elimination of these two effects, since any background screen illumination seriously affects the maximum recordable or observable writing speed. Possible sources of undesired electrons are flecks of material from the getter, cathode, screen, electron gun, and accelerator bands. Since it is practically impossible to fabricate a "clean" cathode-ray tube, some operation on the finished tube is required. The most useful technique is that of "sparking" by means of a high-voltage transient applied between the second anode and the combination of grid, cathode, heater, and focus anode. A current-limiting 15-kv neon-sign transformer will supply the necessary pulses if a Variac and spring-return switch are used to control the voltage (Figure 3). Momentarily closing the switch then applies a high-voltage transient to the gun-structure region, burning off the offending particles deposited in the vicinity. This process is carried out in a very dim light so that the progress made may be followed by noting the incandescence excited at points inside the tube; the brilliance and frequency of the light flashes diminish as the cleaning-up process is continued. Sparking between adjacent accelerator bands, at reduced voltage, is also performed. Since stray emission or bloom may reappear in a tube that has been handled in shipping, the users of such tubes should consider applying the above techniques. Figure 4a shows a trace largely obscured by spurious illumination, and Figure 4b shows the same trace after sparking has been applied. If sparking a tube is not completely successful in eliminating background illumination, the application of a negative (with respect to the second anode) dc voltage of about 50 to 300 volts on the first accelerator band is very effective.

Several changes were made in the basic K1032 electron-gun structure that was used as a starting point for the K1056 development. The size of the intensity-grid aperture was reduced, the focus anode was increased in length, and the spacing between the intensity grid and the preaccelerator portion of anode two was decreased. The combined effect of these changes was to produce a higher beam-current density and a smaller spot size.

In addition to the box-plate design, other variations in deflection-plate size and shape were tried, including different sized plane-parallel, flared, and doubly flared plates. This last type was adopted for the K1056 (Figure 5) in view of its superior transit-time and

* The camera used during the development of the K1056 tube was an Edgerton, Germeshausen, & Grier type 3114 with a Wray f/1.0, 2-in., 4:1 copy-ratio lens.

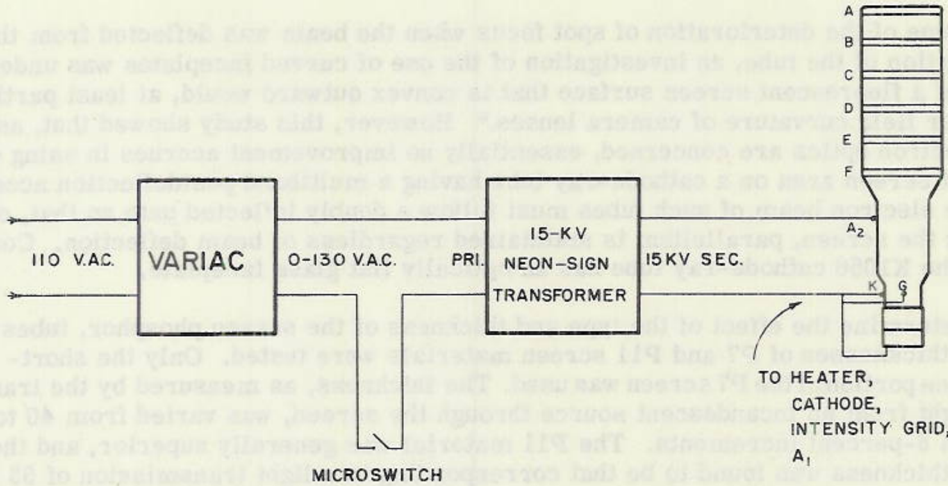

Figure 3 - Circuit diagram for "sparking" process

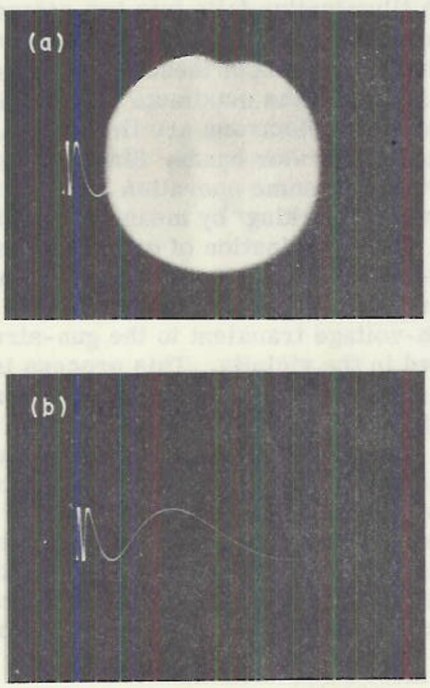

Figure 4 - (a) Trace showing spurious illumination; (b) Same trace after "sparking"

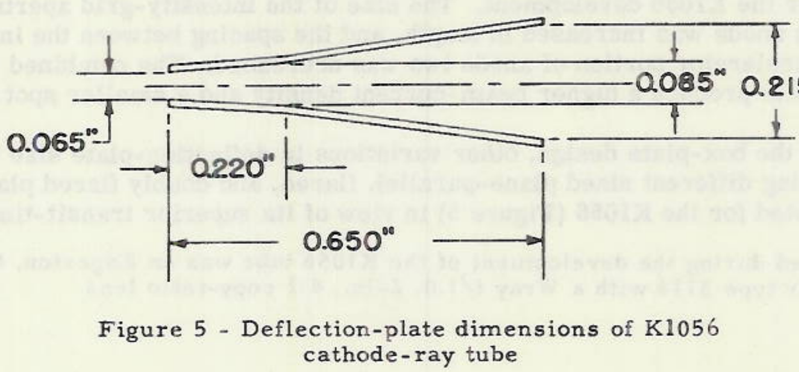

Figure 5 - Deflection-plate dimensions of K1056 cathode-ray tube

frequency-response characteristics as well as its relative freedom from defocusing effects when the beam is deflected. For plane-parallel deflection plates, the transit time of the "first kind" (i.e., through one pair of plates) can be measured by determining the period of the lowest frequency signal that produces zero deflection of the beam.* This is shown by the dashed line in Figure 6. The solid curve shows how the sensitivity of the K1056 tube varies with excitation frequency. There is no frequency at which the deflection falls to zero for the doubly flared plate structure. Transit time of the "first kind" for the K1056 cathode-ray tube has been taken as the period of the frequency at which the dynamic and static (dc) deflection factors are in the ratio of ϵ (2.718). The transit time thus defined through a set of plates is 2.8×10^{-10} sec (corresponding to a frequency of 3,600 Mc) with an anode-two potential of 7.5 kv. †

Transit time between the two pairs of deflection plates (transit time of the "second kind") is an important consideration for cathode-ray tubes used in high-frequency or high-speed transient work. The centers of the two pairs of plates in the K1056 deflection structure are axially spaced 3/4 in. apart, and a metal shield with a rectangular aperture is interposed between the two deflection-plate pairs to minimize cross talk. Both by calculation and by measurement, the transit time between sets of plates is $10.2 \times 10^{-10}/\sqrt{E_{KV}}$ sec, where E_{KV} is the second-anode voltage in kilovolts. This gives a value of 3.73×10^{-10} sec at 7.5 kv. Figure 7 shows the method used for measuring the transit time of the "second kind." Balanced, in-phase, 200-Mc excitation was applied to both pairs of deflection plates, and a photograph of the resulting ellipse and its axes was made. The phase rotation between the two deflection fields is the angle whose sine is the axial distance across the ellipse divided by the total deflection parallel to that axis.

TESTING

A finished K1056 tube is subjected to various "static" tests, including measurement of beam current, orthogonality deviation of the two deflection directions, visual cutoff grid voltage, dc deflection factor, examination of cathode surface, and inspection for spurious electron emission, screen imperfections, and astigmatism. In addition, each tube was tested "dynamically" by operation in an oscilloscope setup. A transient-voltage signal is applied to check for maximum writing-speed capability as well as the ability to display a trace involving a wide range of writing speeds.

CHARACTERISTICS

The K1056 tube characteristics are given in Table 1. Operating without applying astigmatism voltages to the deflection-plate system is satisfactory for many purposes. However, to obtain minimum line width for highest resolution traces, the vertical-deflection plates should be at about -10 volts and the horizontal-deflection plates should be at about +100 volts, both voltages being with respect to the nominal anode-two voltage.

Figure 8a shows a photographic recording made with a K1056 tube displaying a 200-Mc timing wave vertically and the rise of an electronic pulse-generator output

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* Hollmann, H.E., "The Use of the Cathode-Ray Oscillograph at Ultra-High Frequencies," Wireless Engineer and Experimental Wireless, 10:430-433, 1933.

† Transit time through a set of plates was actually determined by applying a fixed-frequency signal, varying the accelerating potential, and noting the potential at which the deflection (corrected for beam velocity) falls to $1/\epsilon$ of the dc deflection. The transit time for any beam voltage may then be obtained from the voltage-velocity relation for the electron.

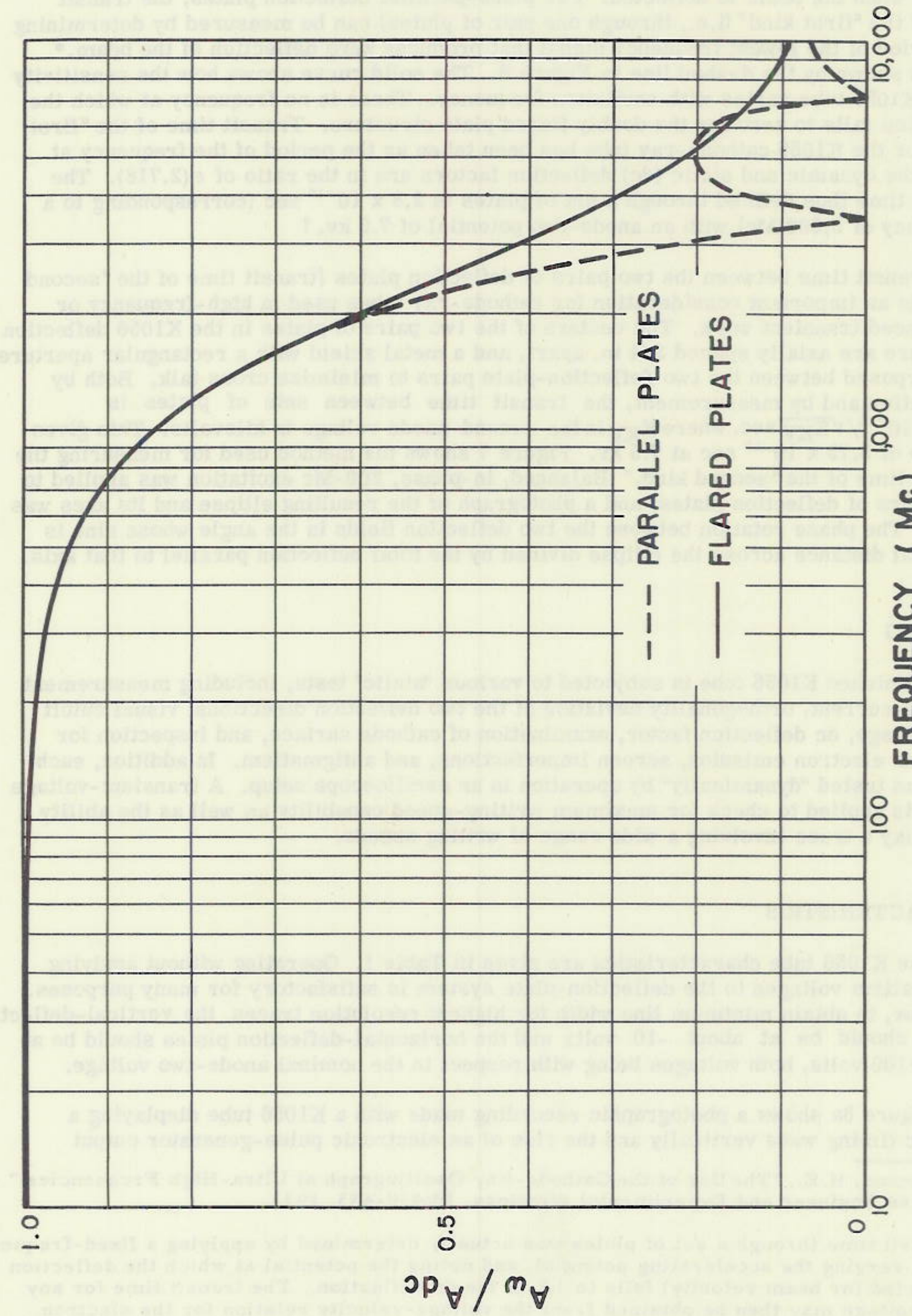


Figure 6 Comparison of frequency responses of parallel and flared deflection plates

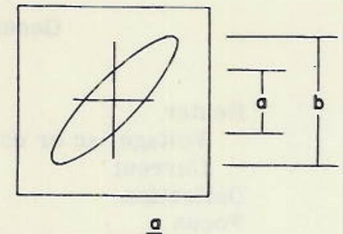
TABLE 1
General Characteristics of the K1056 Tube

Electrical	
Heater	
Voltage, ac or dc	6.3 volts
Current	0.6 ampere
Deflection	Electrostatic
Focus	Electrostatic
Screen	
Phosphor	P11
Fluorescence	Blue
Persistence	Short
Direct interelectrode capacitances, nominal	
Cathode to all other electrodes including filament	4.6 $\mu\mu$f
Grid 1 to all other electrodes	3.7 $\mu\mu$f
D_1 to D_2	1.0 $\mu\mu$f
D_3 to D_4	1.0 $\mu\mu$f
D_1 to all other electrodes except D_2	1.3 $\mu\mu$f
D_2 to all other electrodes except D_1	1.3 $\mu\mu$f
D_3 to all other electrodes except D_4	1.3 $\mu\mu$f
D_4 to all other electrodes except D_3	1.3 $\mu\mu$f
Mechanical	
Over-all length	21 ± 3/8 in.
Greatest diameter of bulb	5 ± 3/32 in.
Minimum useful screen diameter	4 1/4 in.
Bulb contacts (A_3 bands)	Snap-terminal ball contacts
Neck contracts (cathode and grid)	Special lateral contacts
Deflection-plate connections	Coaxial (fit Ucinite J-1357 plug)
Base	Medium 12-pin diheptal
Maximum Ratings *	
Anode 3 voltage (postdeflection accelerator)	35,000 volts dc
Anode 2 voltage	10,000 volts dc
Ratio of anode 3 voltage to anode 2 voltage	5
Anode 1 voltage	5,000 volts dc
Grid 1 voltage	
Negative bias	400 volts dc
Negative peak	<0 volts
Typical Operating Conditions	
Anode 3 voltage †	30,000 volts
Anode 2 voltage	7,500 volts
Anode 1 voltage for focus	2,500 to 2,600 volts
Grid 1 peak voltage	<-20 volts
Grid 1 bias voltage (for visual extinction)	-100 to -150 volts
Deflection factor (D_1-D_2 and D_3-D_4)	210 to 250 dc volts/in.
Spot position (undeflected)	Within 15-mm square

* All voltages are with respect to the cathode

† A_2-A_3 voltage equally divided between the five accelerator bands; i.e., (30 - 7.5)/5 = 22.5/5 = 4.5 kv per band

horizontally. The spot speed varies from zero at the start of the sweep to 1,500 in./μsec near the end of the trace. The trace width varies from 0.018 in. at a spot speed of 50 in./μsec to 0.010 in. at a spot speed of 1,500 in./μsec. Hence the trace speed reckoned in trace widths per second varies from 2.78×10^9 to 1.50×10^{14}. The sensibility of the tube lies in the range of 2 to 4 volts per trace width, the actual value depending on the spot speed at which the trace width is measured. Figures 8b and 8c show recordings of magnetron outputs at 6,500 and 10,000 Mc, respectively. The comparative ease with which such traces can be observed and/or recorded by use of the K1056 cathode-ray tube should be of tremendous aid in the exploration of fast transient phenomena. For example, the build-up of the magnetron output can be examined in Figure 8b to a very high degree of time resolution. Figure 8c clearly shows an intermittent 2,000-Mc amplitude variation of a 10,000-Mc magnetron.



$$T = \frac{1}{f} \times \frac{\sin^{-1}\frac{a}{b}}{360°}$$

WHERE T IS THE TRANSIT TIME

Figure 7 - Measurement of transit time of the "second kind"

The deflection linearity of the K1056 tube is shown in Figure 9, a typical calibration raster.* The deflection-voltage increment between adjacent lines of the raster is 40 volts. Maximum deflection nonlinearity occurs near maximum deflection where the distortion is about 4 percent.

To judge the performance of a cathode-ray tube, a figure of merit has been devised as follows:

$$FM = \frac{E}{2DS},$$

where FM is the figure of merit; E is the peak signal voltage available, equal to or less than the full-screen deflection voltage; D is the deflection factor in volts per inch; and S is the spot size in inches. This figure of merit is numerically equal to the resolution of the tube display in terms of the trace width. Since the trace width varies with the trace speed, a choice must be made as to where to measure the trace width. For example, on the trace in Figure 8a, if the width were taken at 50 in./μsec, a somewhat low figure of merit would be obtained since the line width at higher speeds may be reduced by a half. Nevertheless, on this basis, the average K1056 tube, having an average 0.019-in. line width at 50 in./μsec, has a figure of merit of

$$FM = \frac{940}{2 \times 235 \times 0.019} = 105$$

for full-screen (4-in.) deflection. The figure of merit for the highest speed portion of the trace (or the figure for any trace with a small range of speeds) would be 200 or more.

ACKNOWLEDGMENTS

Construction of experimental and production K1056 tubes was done at the DuMont laboratories under the supervision of Messrs. Stanley J. Koch, Robert E. Rutherford, Sr., and Robert E. Rutherford, Jr. The authors' portion of the project was assisted by Dr. Wayne C. Hall and Mr. N. W. Mathews of the Electricity Division, Naval Research Laboratory.

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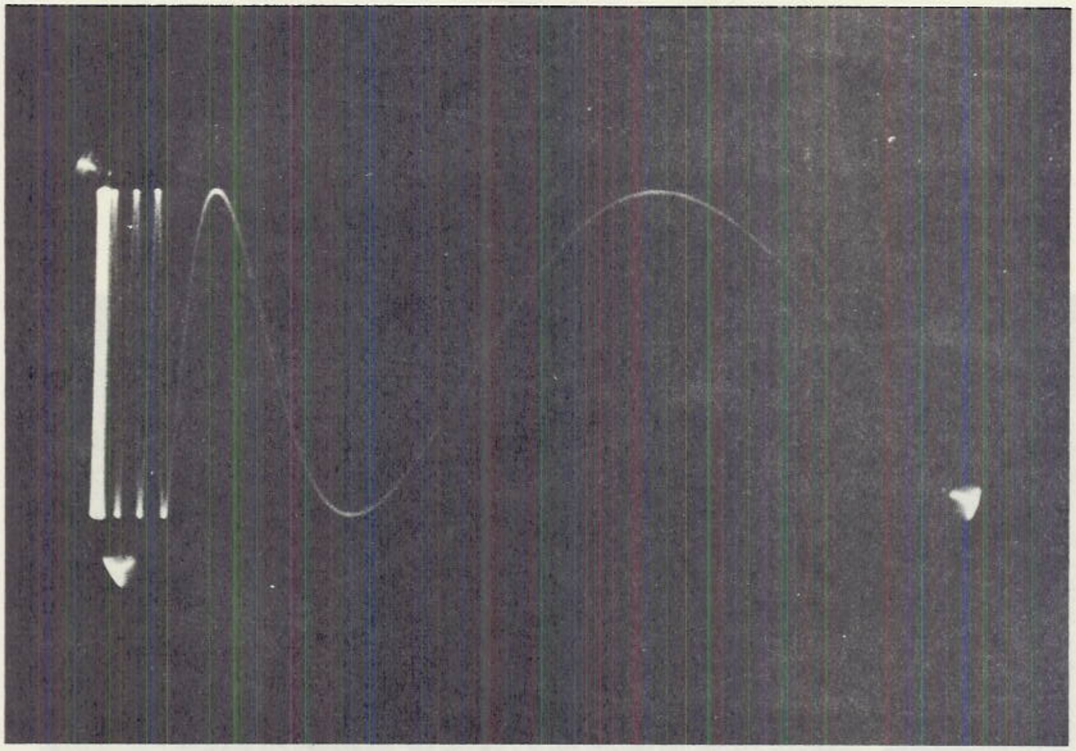
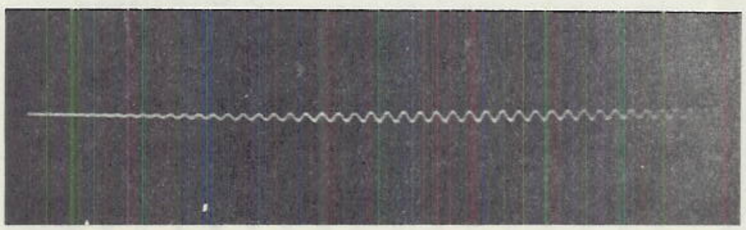
* Robinson, G. B., and Van Allen, R. L., "Precision Measurements with a Cathode-Ray Oscilloscope," Naval Research Laboratory report (to be published).



(a)



(b)

(c)

Figure 8 - Sample photographs of K1056 cathode-ray-tube displays. Vertical deflection is (a) 200 Mc; (b) 6,500 Mc; (c) 10,000 Mc.

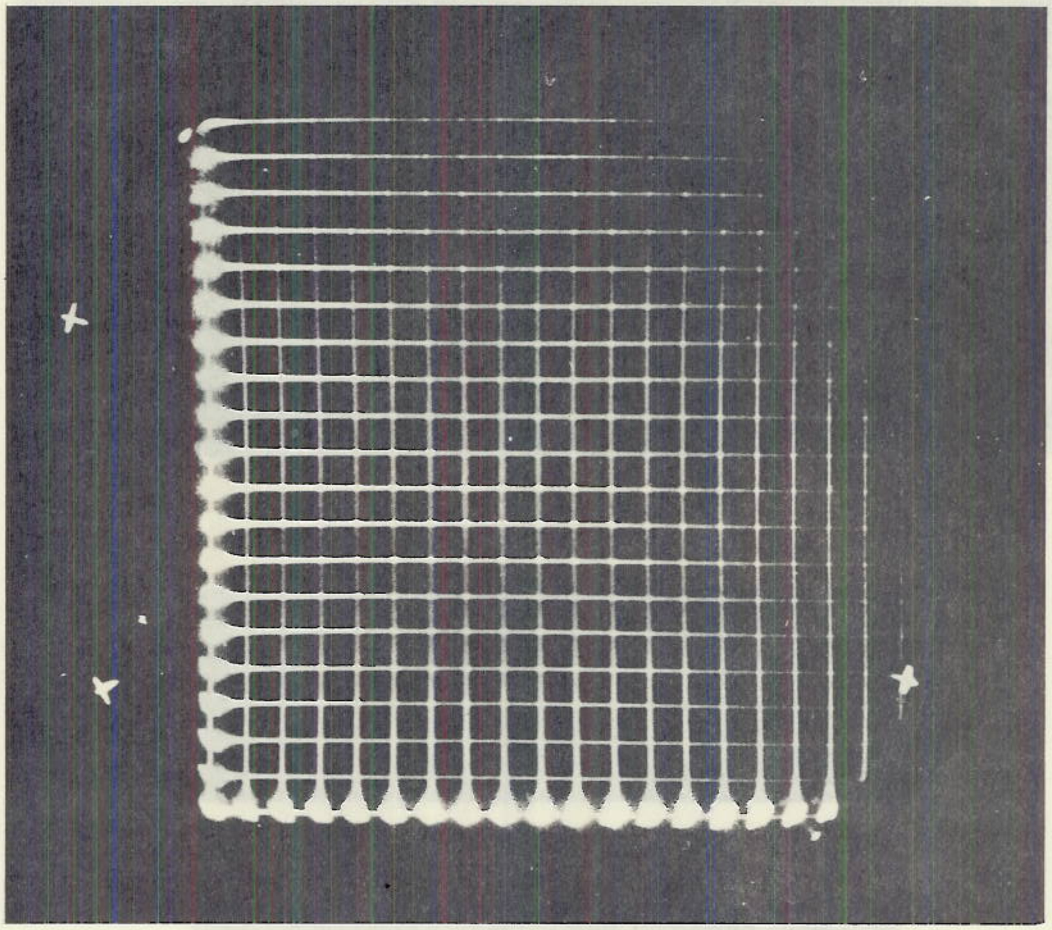


Figure 9 - Deflection-calibration recording

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